Effect of Mixed Pollutants on Soil-Plant Microcosms

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EFFECT OF MIXED POLLUTANTS ON SOIL-PLANT MICROCOSMS

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EFFECT OF MIXED POLLUTANTS ON SOIL-PLANT MICROCOSMS

by

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ABSTRACT

Experiments were initiated to determine the long-term effects of continued deposition of a complex of pollutants on the forest system in the Athabasca Oil Sands area. A plant-soil microcosm (jack pine-Dystric Brunisol) had various pollutant mixtures added to its surface at levels representing up to 104 years of deposition. No measureable plant responses have been detected to date, however, measurements of both plant and soil responses are continuing.

1. INTRODUCTION

In the Athabasca Oil Sands area in northeastern Alberta, very little obvious damage to the forest ecosystem has been related to air pollution from Suncor Inc. and Syncrude Canada Ltd. (Addison 1980). Suncor has been operating at its present location (ca. 30 km north of Fort McMurray) since 1967 and for much of that time has emitted about 150 t of sulphur per day (Shelfentook 1978). In addition, particulates containing aluminum, iron, vanadium, and nickel have been emitted to the atmosphere at the rate of approximately 40 t per day (Shelfentook 1978). Syncrude Canada Ltd., when it is in full production is expected to emit about 130 t of sulphur and 110 t of NO_x per day. Because of the magnitude and the combination of types and form of the emissions, the potential for serious impact on the forest ecosystem is very great.

In order to address this problem, a study was designed to 1) determine the impact of pollutant mixtures on native soils and their ability to support dominant tree species of the area and 2) develop a predictive capability with respect to long-term effects of industrial emissions on the forest system in this area.

In year 1 of this study (1980-81), the aim was to determine the influence of elevated levels of soluble pollutant mixtures on the capability of the soil to support jack pine. The use of soluble forms of the pollutants at levels up to 100 times the normal depostion rates in the area was an attempt to examine the worse possible case. One would expect that field responses would be less.

2. MATERIALS AND METHODS

2.1 COLLECTION OF EXPERIMENTAL MATERIAL

Approximately 1000 intact soil cores 15 cm in diameter by 20 cm deep were collected from a relatively uncontaminated area about 12 km north of Suncor Inc. in the Athabasca Oil Sands area (LSD 01, 19, 93, 10 W4). The site was level to very gently sloping to the northwest and was rapidly drained. A mixedwood community covered the area and was dominated by jack pine (*Pinus banksiana* Lamb.) and paper birch (*Betula papyrifera* Marsh) in the upper stratum, green alder (*Alnus crispa* (Ait.) Pursh) and pin cherry (*Prunus pensylvanica* L.f.) in the high shrub stratum and bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) and ground lichens (*Cladina mitis*) on the surface.

Two soil pits were dug in the area and duplicate samples of each horizon were collected. Soil characteristics (physical and chemical) were determined using methods described by the Canadian System of Soil Classification (1974) and Addison (1980).

The jack pine seed used in the experiments was collected from several mature trees in the vicinity of Anzac, about 30 km south of Fort McMurray. The seed had a viability of 97%.

2.2 EXPERIMENT 1

A total of 105 cores of soil were thoroughly soaked in deionized water for several days and allowed to drain for 10 days. Water soluble forms of aluminum, nickel, vanadium, and SO_4 were applied to the core surface in a fine mist in the combinations and concentrations listed in Table 1. Deposition rates for the applied pollutants were calculated from Barrie (1978). Thirty jack pine seeds were sown in each core at a depth of 1.5 cm. This depth represented the average depth of the LFH-mineral soil interface.

The soil cores were randomly numbered and placed in a controlled environment chamber that had constant 18°C temperature and a 15°C dew point temperature. An 18-h photoperiod was provided from a mixture of

Table 1. Combinations and concentrations of soluble elements added to soil columns from the Athabasca Oil Sands area in Experiment 1. Deposition rates are based on Barrie 1978.

Treatment[a]	Form	Deposition Rate (mg m^{-2} y^{-1})	Deposition Equivalent (y)	Compounds Added (mg per pot)	Number of Replicates
Al	$Al(NO_3)_3 \cdot 9H_2O$	5.472	13	KOH- 0.8	5
			26	1.6	5
			52	3.2	5
Ni	$Ni(NO_3)_2 \cdot 6H_2O$	4.092	13	-	5
			26	-	5
			52	-	5
S	H_2SO_3	306.6	13	KOH-15.8	5
			26	31.3	5
			52	62.6	5
V	V_2O_5	36.282	13	KOH- 31.0 HNO_3-21.2	5
			26	62.0 42.4	5
			52	124.0 84.7	5
Ni+V	b		26	KOH- 62.0 HNO_3-42.4	5
Ni+S			26	KOH-31.3	5
V+S			26	KOH- 93.3 HNO_3-42.4	5
Ni+V+S			26	KOH- 93.3 HNO_3-42.4	5
Treated Control	KOH HNO_3		-	KOH-125.0 HNO_3-85.0	5
Control					20

a pH adjusted to 1.9 for S and 5 for Al, Ni, and V solutions.
b Mixtures have same forms as above and deposition rates equivalent to 26 years.

sodium and multi-vapor lamps. Photon flux gradually increased from 0 to 500 μMol $m^{-2}s^{-1}$. Cores were watered at 3-5 day intervals to ensure that there was freely available water for the seedlings. Measured amounts of water were used to prevent excessive drainage and the weights of several cores were measured regularly.

2.2.1 Analysis of Response

The number of seedlings per core was recorded 9 weeks after planting. The first four seedlings to emerge were marked and height was measured (mm) weekly. The interval between measurements was gradually increased to one month as the seedlings matured.

After 9 weeks, all seedlings except the 4 designated for growth measurements were harvested and analyzed for peroxidase activity and protein content. The extractions and assays of peroxidase activity in needle tissue were done as described by Malhotra and Khan (1979). Protein content of the enzyme extracts were determined according to Lowry *et al.* (1951) after precipitation with trichloroacetic acid. Needle tissue was also analyzed for element content using methods described by Addison (1980).

A second harvest of plant material and analysis was carried out 17 weeks after planting. In this sampling, one of the four seedlings selected for growth measurements was used for analysis of biological response and element content.

2.3 EXPERIMENT 2

A second experiment has been initiated with 200 soil cores. This experiment includes treatment of soil cores with 1) the pollutants described in section 2.2 and NO_3 and 2) pollutant concentrations equivalent to 26, 52, and 104 years of deposition (Table 2). Because of the number of cores involved, this experiment is being carried out in the greenhouse (temperature 20°C; 16 h photoperiod of natural light supplemented by cool white fluorescent lamps; 35% relative humidity). Twenty-five jack pine seeds were planted in each core. Aside from the changes mentioned above, the experimental procedures and maintenance were essentially the same as described in section 2.2.

Table 2. Combinations and concentrations of soluble elements that were added to soil columns from the Athabasca Oil Sands area in Experiment 2.

Treatment	Form	Deposition Rate (mg m^{-2} y^{-1})	Deposition Equivalent (y)	KOH Added (mg per pot)	Replicates
Ni	$NiNO_3$	4.092	26		5
			52		5
			104		5
N	HNO_3	116.6	26		5
			52		5
			104		5
S	H_2SO_3	306.6	26		5
			52		5
			104		5
V	V_2O_5	36.282	26	62.0	5
			52	124.0	5
			104	248.0	5
N+S	[a]		52		5
			104		5
N+V			52	124.0	5
			104	248.0	5
N+Ni			52		5
			104		5
S+V			52	124.0	5
			104	248.0	5
S+Ni			52		5
			104		5
V+Ni			52	124.0	5
			104	248.0	5
N+S+V			52	124.0	5
			104	248.0	5
N+S+Ni			52		5
			104		5
S+Ni+V			52	124.0	5
			104	248.0	5
N+S+V+Ni			52	124.0	5
			104	248.0	5
Control					40

[a] Mixtures have the same forms as individual pollutants.

2.4 SEED GERMINATION

Jack pine seed was placed in petri dishes between filter paper moistened with solutions of Al, Ni, SO_4, V, and NO_3. The concentrations used were computed using the deposition rates from Barrie (1978), assuming 50 cm of precipitation annually in the area. The treatments represented the average, 10, 100 and 1000 times the yearly concentration in precipitation (Table 3). A treatment with HCl was also used to determine the effect of pH (Table 3). Ten seeds were placed in each petri dish and five replicate dishes were used for each treatment. The number of seeds that had germinated and the root length (mm) after nine days of incubation at 20°C in the dark was recorded.

2.5 ANALYSIS OF TREATED SOIL

One core that had been treated with Ni, SO_4 and V was analyzed for an initial estimation of rate of migration of the added elements. The core, after 15 weeks of the experiment, was divided into 5 samples (LFH, Ah, Ae, Bm_1, Bm_2) at depths of 1, 2.5, 7.5, and 15 cm. Extraction by both NH_4Ac and HCl (Baker 1980) were carried out as well as a total digest by HF (Addison and Baker 1980). Atomic Absorption Spectrophotometry was used for the analysis of the added pollutants Ni, Al, and V as well as for Ca, P, Mg, and K. Total sulphur was estimated by a modified Johnson-Nishita method (Carson *et al.* 1972).

Table 3. Concentrations of solutions used in seed germination studies.

Element			Treatment				
			Control	Average	10X	100X	100X
Aluminum	pH		5.0	3.9	3.5	3.0	2.0
	Concentration[a]		0	0.011	0.11	1.1	10.8
Nickel	pH		6.2	6.0	5.8	4.7	3.7
	Concentration		0	0.0081	0.081	0.81	8.1
Nitrate	pH		5.8	4.7	3.6	2.7	1.8
	Concentration		0	0.2	2.3	22.9	229.1
Sulphate	pH		5.8	4.3	3.3	2.3	1.5
	Concentration		0	0.6	6.0	60.4	603.5
Vanadium	pH		6.1	3.6	2.8	2.0	1.3
	Concentration		0	0.065	0.65	6.5	65.0
HCl	pH	5.6	4.9	4.0	3.0	2.0	1.25

a Concentration is in ppm.

3. RESULTS AND DISCUSSION

All components of this study are still being updated and the results described below represent only the initial findings. Little can be interpreted as of yet owing to both the long-term nature of these experiments and the tentativeness of the present data.

3.1 NATIVE SOILS

The soils collected for experimentation were Degraded Dystric Brunisols (CSSC 1974). This soil type is characteristic of the jack pine stands found in the vicinity of oil sands operations (Addison 1980). Analysis of the total element content of the soil (Table 4) indicated slightly higher sulphur levels than observed earlier in the area (Addison 1980) but, the levels were well within normal soil ranges (Chapman and Pratt 1961). The concentrations of other elements were also in the normal range for this nutrient poor and coarse textured soil type from this area (Turchenek and Lindsay 1978). A moisture retention curve (Figure 1) of the mineral soil component of the cores also reflected the lack of fine soil particles in this sandy soil.

The capability of the soil to retain water was very little and even at .01 MPa, water content was less than 6% of soil oven dry weight. The high value of water content at 1.2 MPa is inconsistent and is being repeated at this time.

3.2 EXPERIMENTAL CONDITIONS

Water content of the cores gradually decreased over the first 120 days of the experiment under the 3-5 day watering regime (Figure 2). This reduction, however did not produce any signs of water deficit in the seedlings. To avoid water deficit in plants due to excessive soil drying, watering frequency of the cores was increased. This practice produced an increase in the water content of the cores to a level slightly below the original (Figure 2).

3.3 PLANT RESPONSE

No response of the plants to the various treatments could be detected in either percent establishment or in the initial nine weeks

Table 4. Physical and chemical descriptions of soil material collected for experimental manipulation from the Athabasca Oil Sands area. Values are means ±95% confidence limits.

Horizon	Depth (cm)	Description	pH ($CaCl_2$)	CEC[a] (pH 5.2) mg 100 g^{-1}	Element Content								
					S	P	Ca	Mg	K	Al	Fe	Mn	Zn
					ppm								
LFH	+3-0	Dark grayish brown (10YR 4/2 m), very dark gray (10YR 2.5/1 d); semidecomposed organic matter; many fine and medium roots; abrupt, smooth boundary; 0.5 to 4 cm thick.	4.4 ±.2	39 ±10	583 ±40	575 ±189	6300 ±1855	906 ±163	3350 ±755	8063 ±1603	5275 ±728	1383 ±310	124 ±12
Ahe	0-6	Very dark grayish brown (10YR 3/2 m), grayish brown (10YR 5/2 d); sandy loam; single grain; loose, very friable, plentiful medium roots; abrupt, smooth boundary; 5 to 7 cm thick.	4.2 ±.5	7 ±4	146 ±44	331 ±60	2175 ±614	526 ±49	3950 ±113	8750 ±874	6325 ±773	764 ±330	52 ±6
Ae	6-11	Reddish yellow (7.5YR 6/6 m), very pale brown (10YR 7/4 d); sandy loam; single grain; loose, very friable; plentiful fine to medium horizontal roots; clear, smooth boundary; 4 to 7 cm thick.	4.5[b]	2	111	100	1125	328	3438	6938	4575	123	50
Bm	11-46	Reddish yellow (7.5YR 6/10 m, 6/6 d), loamy sand; single grain; loose; very fine to medium vertical roots; gradual wavy boundary; 33 to 39 cm thick.	4.5 ±.1	2 ±.2	105 ±26	238 ±124	1663 ±334	685 ±117	4044 ±921	11156 ±1951	10500 ±1904	129 ±25	49 ±8
C	46+	Brownwish yellow (10YR 6/10 m), yellow (10YR 7/8 d); sand; single grain; loose; very few, fine to very fine vertical roots.	4.6 ±.1	2 ±.1	95 ±24	138 ±76	1450 ±195	566 ±116	3656 ±291	9188 ±257	6663 ±3423	118 ±31	39 ±5

a CEC - Cation Exchange Capacity.
b Only two replicates.

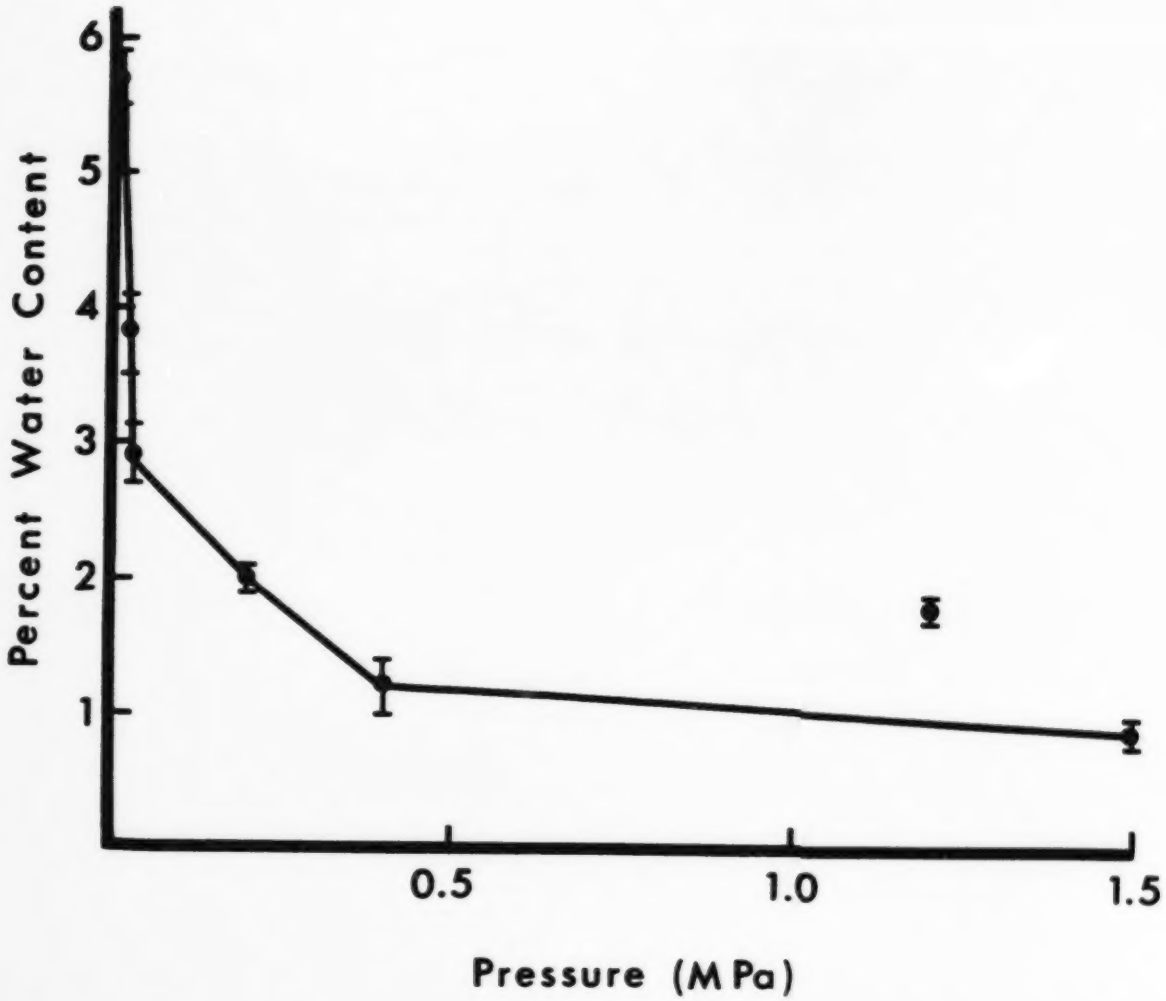

Figure 1. Water retention curve for mineral soil component of experimental soil columns from the Athabasca Oil Sands.

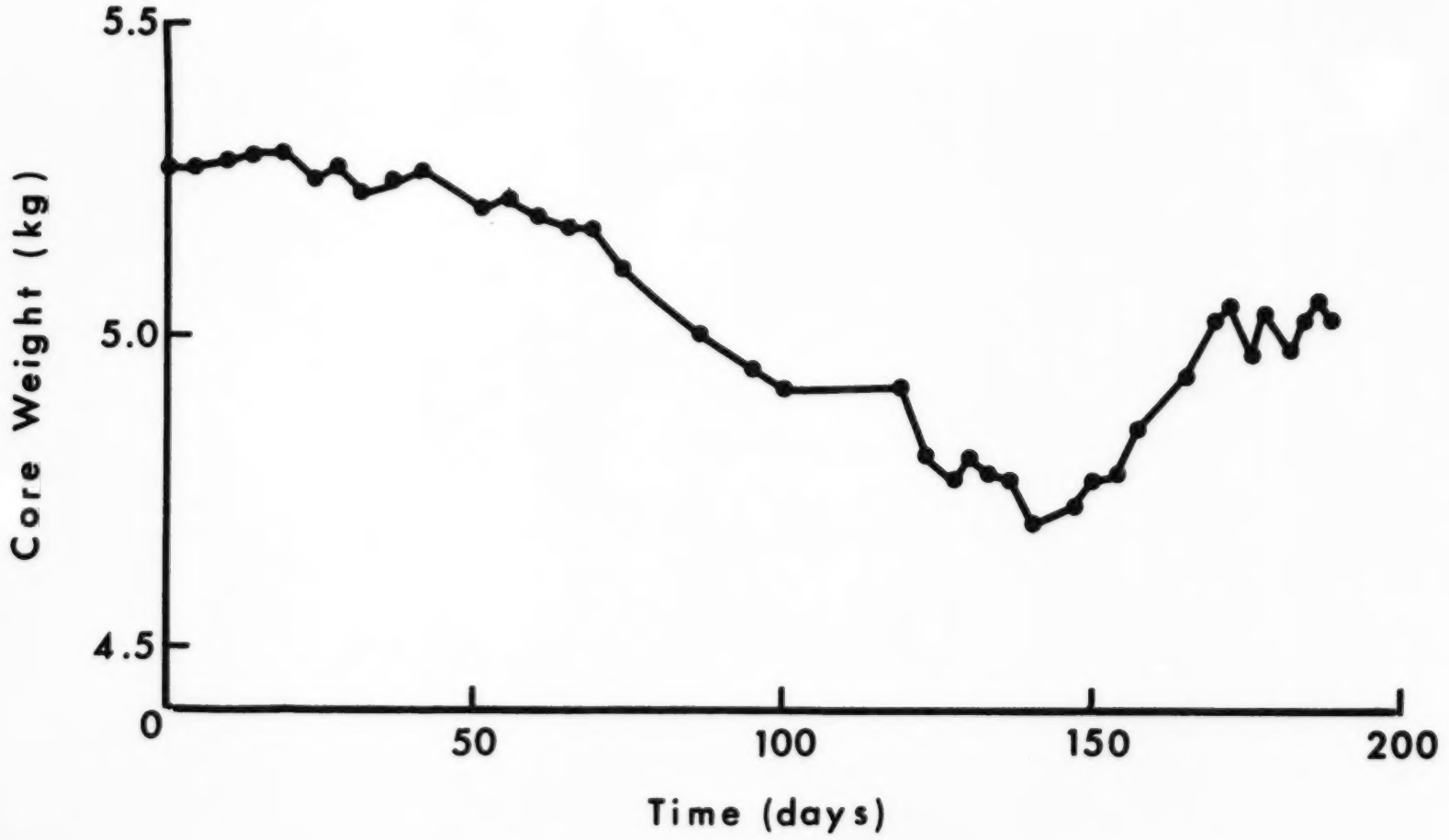

Figure 2. Mean weight of five soil columns during experiment 1.

growth rate (Table 5). Establishment rates were very low in all cases. Since the seed used had a 97% viability, the low rate of seedling establishment in both control and treated cores is attributed to the soil environment.

A slight response to the treatment was shown by peroxidase activity. The average activity for each treatment was higher than the control in almost all cases (Table 5). Among the treatments, plants exposed to nickel showed the maximum increase in peroxidase activity although no correlation between applied concentration of metal and increase in activity could be made. Furthermore, the differences in peroxidase activity were not statistically significant at the 5% level. Pollutant mixtures also did not demonstrate any additive, antagonistic or synergistic responses as measured by peroxidase activity.

Seventeen weeks after planting, the pattern of plant response was quite similar to that of the 9 week ones. Peroxidase activity of the treated core seedlings was higher than control but the differences were not sufficiently great to provide much confidence (Table 6). The content of soluble proteins showed no significant difference between control and any of the treatments. In hydroponically-grown pine seedlings, treatment with 1 to 10 ppm of Ni and B produced marked stimulation in peroxidase activity (Malhotra and Khan 1979, 1980). The absence of such an increase in peroxidase activity of plants grown in treated cores indicated that in the soil system, the elements added were rendered nontoxic owing to changes in either their form or availability. The absence of any appreciable uptake of the elements added by the pine seedlings points to a reduction in availability presumably through complexing or bonding in the organic soil layer. Initial analysis of elements in a treated core indicated that by far the majority of the elements added to the column remained in the top 1 cm of the soil. This was the case for both heavy metals (63%) and sulphur (94%). Since jack pine seeds were planted at a depth of 1.5 cm, the lack of response of the seedling may be as a result of not being exposed to the pollutants added. This is evident by the analysis of these pollutants in the plant tissue because the content of added pollutants and other elements in the needle tissue did not differ substantially between control and treatments (Table 5). Only the sulphur content of

Table 5. Plant response to experimental conditions after 9 weeks of exposure. Mean ±95% confidence limits.

Treatment Element	Yrs	% Establishment	Growth Rate (mm d^{-1})	Peroxidase Act (ΔOD min^{-1} g^{-1} dry wt)	Element Content in Plant Tissue							
					S	P	Ca	Mg	K	Al	Ni	V[a]
					ppm							
Al	13	42.7 ± 23.7	1.57 ± 0.24	53.3 ± 14.2	884	1 900	1 425	1 210	9 050	240.0	3.0	-
	26	31.3 ± 27.0	1.63 ± 0.18	51.5 ± 97.8	686	1 470	1 764	1 029	8 702	206.0	4.0	-
	52	66.7 ± 32.7	1.91 ± 0.29	46.9 ± 26.7	687	1 600	1 200	880	8 080	220.0	3.0	-
Ni	13	32.0 ± 26.0	1.56 ± 0.19	65.0 ± 15.5	786	1 500	1 275	930	9 030	250.0	7.0	-
	26	28.0 ± 14.8	1.53 ± 0.19	60.3 ± 4.8	766	1 404	1 287	920	9 922	218.0	6.0	-
	52	12.7 ± 11.1	1.55 ± 0.28	46.5 ± 7.7	-	-	-	-	-	-	-	-
S	13	38.7 ± 19.5	1.88 ± 0.18	43.1 ± 7.1	982	1 700	1 650	930	9 610	190.0	2.0	-
	26	31.7 ± 32.6	1.39 ± 0.24	45.5 ± 29.5	566	1 344	1 344	922	11 001	250.0	2.0	-
	52	25.3 ± 12.3	1.66 ± 0.26	50.6 ± 41.8	1 037	1 848	1 419	1 030	9 801	264.0	4.0	-
V	13	32.0 ± 13.9	1.80 ± 0.26	73.1 ± 25.4	638	1 700	1 975	990	8 340	120.0	7.0	-
	26	36.0 ± 18.8	1.62 ± 0.19	54.1 ± 4.7	656	1 875	1 313	1 125	9 888	313.0	13.0	-
	52	32.0 ± 19.6	1.71 ± 0.29	60.0 ± 16.9	793	1 800	1 550	940	10 320	120.0	2.0	-
Ni+V	26	30.7 ± 18.4	1.57 ± 0.26	55.0 ± 21.9	898	1 350	1 654	1 066	10 422	176.0	8.0	-
Ni+S	26	23.3 ± 23.0	1.34 ± 0.34	51.2 ± 11.5	1 061	1 600	1 650	1 220	10 500	280.0	4.0	-
V+S	26	35.3 ± 30.0	1.97 ± 0.27	53.7 ± 50.7	1 056	1 600	1 375	1 040	10 050	200.0	1.0	-
Ni+V+S	26	28.0 ± 22.4	2.16 ± 0.27	65.1 ± 26.8	1 006	1 600	1 700	1 000	11 440	120.0	3.0	-
Treated Control	-	31.3 ± 34.5	1.70 ± 3.60	70.9 ± 26.8	344	3 000	1 550	930	11 270	130.0	7.0	-
Control	-	30.7 ± 8.2	2.01 ± 0.20	46.8 ± 21.0	794	1 744	1 526	1 085	9 800	230.0	4.0	-

a [V] below detectable limit.

Table 6. Plant response to experimental conditions after 17 weeks of exposure. Mean ±95% confidence limits.

Treatment Element	Yrs	Growth Rate (mm d^{-1})	Peroxidase Act (ΔOD min^{-1} g^{-1} dry wt)	Protein (mg g^{-1} dry wt)	Element Content in Plant Tissue (ppm) S	P	Ca	Mg	K	Al	Ni	V[a]
Al	13	0.66 ± 0.06	65.7 ± 15.2	25.0	957	1400	1900	980	5880	140	6.0	-
	26	0.80 ± 0.09	66.3 ± 35.3	26.1	684	1100	1485	870	5490	200	6.0	-
	52	0.66 ± 0.07	66.4 ± 25.9	25.1	492	875	1625	850	4212	163	4.0	-
Ni	13	0.77 ± 0.10	51.4 ± 14.0	24.7	591	1100	1825	850	4860	240	3.0	-
	26	0.72 ± 0.07	56.4 ± 20.0	26.5	656	1000	1300	740	5080	230	2.0	-
	52	0.82 ± 0.15	57.6 ± 28.7	22.9	656	1300	1475	880	6500	110	7.0	-
S	13	0.73 ± 0.07	82.4 ± 26.8	26.6	711	1000	1725	890	4720	110	24.0	-
	26	0.82 ± 0.11	95.3 ± 89.7	26.4	1043	1417	1608	872	6540	185	20.0	-
	52	0.76 ± 0.11	87.6 ± 37.6	26.7	766	1000	1550	780	4390	160	3.0	-
V	13	0.73 ± 0.10	80.6 ± 26.7	29.7	656	1100	1600	820	4870	200	2.0	-
	26	0.71 ± 0.08	73.9 ± 15.5	26.1	602	1000	1575	890	4780	200	3.0	-
	52	0.68 ± 0.08	79.0 ± 20.9	29.7	629	1000	1925	940	5290	250	0.0	-
Ni+V	26	0.74 ± 0.09	58.2 ± 30.3	28.6	875	1200	1575	830	6070	150	0.0	-
Ni+S	26	0.69 ± 0.15	67.6 ± 45.0	26.4	656	1300	1600	900	5720	190	7.0	-
V+S	26	0.84 ± 0.13	54.7 ± 19.0	23.2	711	1200	2050	1020	5470	180	0.0	-
Ni+V+S	26	0.83 ± 0.07	75.2 ± 21.1	27.7	875	1200	1500	970	6190	210	0.0	-
Treated Control	-	0.82 ± 0.08			996	1000	1778	840	4920	100	2.0	-
Control	-	0.73 ± 1.35	53.1 ± 23.2	27.4	695	1140	1485	850	5040	174	3.0	-

a [V] below detectable limit.

tissue was higher in plants grown with 13 and 52 year and all S combination treatments. This increase, however, was not consistent and could not be related to any biological response. Furthermore, the usefulness of Al, Ni, and V analyses as a measure of seedling uptake was complicated by their low levels in the tissue and the low sensitivity of atomic absorption spectrometry at such levels.

3.4 SEED GERMINATION

Seedling establishment in the soil cores was exceptionally low (Table 5) in spite of both the optimum growing conditions and the high viability of the seed source. To test whether the presence of various pollutants would affect germination and initial root growth, seeds were exposed to various concentrations of pollutants. Germination was not greatly affected up to 100 times the annual average concentration of pollutants (Table 7). The pollutants, however, significantly inhibited root growth at high concentrations and low pH. The response of the plants appeared to be almost totally controlled by pH and with the exception of nickel, no response occurred above pH of 3.0 (Table 7).

Soil pH in the core experiment was about 4.5 and hence, the low seedling establishment can not be due to pH. It appears therefore, that poor seedling establishment in these soil cores may be due to some other soil factors. Studies on the effect of factors such as organic layer nature and thickness are currently underway.

Table 7. Percent of germination and root length of jack pine after ten days of exposure to various concentrations of pollutants.

Pollutant		Treatment				
		Control	Annual Average	10X	100X	1000X
Aluminum	Length (mm)	26.5 ± 2.3	19.8 ± 2.7	25.4 ± 2.7	14.8 ± 1.5	1.1 ± 0.3
	% Germination	90	72	72	82	80
	mg L^{-1}	0	0.011	0.11	1.1	10.8
	pH	5.0	3.9	3.5	3.0	2.0
Nickel	Length (mm)	29.2 ± 1.4	26.2 ± 1.2	22.9 ± 3.1	22.4 ± 1.5	8.2 ± 0.8
	% Germination	90	78	92	94	92
	mg L^{-1}	0	0.0081	0.081	0.81	8.1
	pH	6.2	6.0	5.8	4.7	3.7
Nitrate	Length (mm)	27.8 ± 1.9	26.8 ± 2.9	28.6 ± 1.7	11.5 ± 2.2	2.5 ± 0.3
	% Germination	92	92	98	90	86
	mg L^{-1}	0	0.2	2.3	22.9	229.1
	pH	5.8	4.7	3.6	2.7	1.8
Sulphate	Length (mm)	28.1 ± 2.3	27.9 ± 2.4	22.0 ± 2.6	4.0 ± 0.5	1.2 ± 0.3
	% Germination	90	84	88	88	76
	mg L^{-1}	0	0.6	6.0	60.4	603.5
	pH	5.8	4.3	3.3	2.3	1.5
Vanadium	Length (mm)	26.4 ± 1.5	26.0 ± 1.4	17.8 ± 1.3	2.6 ± 0.5	0
	% Germination	82	85	74	86	0
	mg L^{-1}	0	0.065	0.65	6.5	65
	pH	6.1	3.6	2.8	2.0	1.3
HCl	Length (mm)	30.4 ± 2.3	31.1 ± 2.1	27.5 ± 2.2	27.3 ± 1.9	3.1 ± 0.6	0
	% Germination	100	92	92	98	88	0
	pH	5.6	4.9	4.0	3.0	2.0	1.25

4. CONCLUSIONS

Because of the interim nature of the results, it is not possible to make any major conclusions at the present time. A number of factors that can affect both plant and soil responses have yet to be assessed. High pollutant deposition to the soil surface did not produce drastic effects on plant responses on a short-term basis.

The use of a soil-plant microcosm, however, does appear to have great potential as an experimental system with which to study the major factors controlling the response of the soil-plant system to pollutant deposition. The long-term experiments currently being carried out play an important role in identifying areas where understanding is lacking and in guiding research into those areas.

5. ONGOING AND FUTURE WORK

1. Experiment 1 - Determine the effect of treatments (Table 1) on:
   a. net photosynthesis of pine seedlings,
   b. protein content, peroxidase activity, and element content of seedlings after eight months of exposure,
   c. soluble, exchangeable, and total nutrient and pollutant levels at various depths in the soil column, and
   d. carbon dioxide efflux from the soil column.

2. Experiment 2 - will follow the direction of experiment 1 with the changes as noted above. This experiment will be maintained for a longer period of time to permit greater migration of elements in the soil system and interaction with plants.

3. Continued studies on seed germination and initial root growth with efforts to distinguish pH and pollutant effects and their interactions.

4. Study the factors controlling seedling establishment in natural and treated soil columns.

5. Study the pattern of pollutant migration and availability in the soil system.

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